METHOD FOR REDUCING THE EFFECTS OF PRINTHEAD CARRIER DISTURBANCE DURING PRINTING WITH AN IMAGING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the invention.

The present invention relates to an imaging apparatus, and, more particularly, to a method for reducing the effects of printhead carrier disturbance during printing with an imaging apparatus.

2. Description of the related art.

An imaging apparatus may be, for example, a printer or a multifunction unit. Such a printer may be, for example, an ink jet printer having an ink jet print engine. Such a multifunction unit may include an ink jet print engine, and is configured to perform standalone functions, such as copying or facsimile receipt and transmission.

Typically, an imaging apparatus having an ink jet print engine includes a reciprocating printhead carrier that transports one or more ink jet printheads across the print medium along a bi-directional main scanning direction, also commonly referred to as the horizontal direction. Printing may take place during one or more unidirectional scans, i.e., passes, of the printhead carrier, e.g., a left-to-right scan and/or a right-to-left scan.

An image is formed on a print medium by ejecting ink from at least one ink jet printhead to form a pattern of ink dots on the print medium. Typically, each ink jet printhead will include one or more columnar nozzle arrays, each having a plurality of ink jet nozzles for expelling the ink. In ink jet printing, it is common to use the ink colors of cyan, magenta, yellow and black, in full strength and/or diluted forms, in generating color prints.

An indexing mechanism is used to incrementally advance the print medium in a sheet feed direction, also commonly referred to as a sub-scan direction or vertical direction, through a printable region (also sometimes referred to as a print zone) between passes of the printhead carrier in the main scanning direction, or after all data intended to be printed on the print medium has been completed.

One type of printing defect common to ink jet print engines is often referred to as vertical banding. Vertical banding defects in multi-color printing are typically observed as a repeating pattern of vertical light bands and vertical dark bands in a

printed image, and may also appear in multi-color form similar to that of a rainbow. Vertical banding may also appear in a more rainbow-like repeating pattern. In either case, the printing defect resembles vertical blinds or bands. Vertical banding defects are particularly noticeable in high density ink jet printer printouts, such as when attempting to produce photographic quality printouts, but also can be observed in lower density printouts as well. It has been recognized that printhead carrier disturbances, in the form of printhead carrier vibration, for example, contribute to vertical banding.

Fig. 1 illustrates the general concept of the printhead carrier disturbance, showing the velocity and carrier disturbance versus carrier position during a printhead carrier movement across the print medium (i.e., in the main scanning or X direction). Waveform 8 depicts printhead carrier velocity, in inches per second (ips). Waveform 9 depicts an exemplary printhead carrier disturbance in terms of generated dot placement error in microns (um) in the sub-scanning direction, i.e., the Y-direction, at a disturbance frequency of 50 hertz (Hz), i.e., with a period of 20 milliseconds (ms). Thus, as the printhead carrier moves across the print medium in the main scanning direction, i.e., the X-direction, the printhead carrier can oscillate, which causes ink dot placement errors in the sheet feed direction, i.e., the Y-direction. This phenomenon is detrimental to print quality, yielding vertical banding and varying grain artifacts.

What is needed in the art is a method for reducing the effects of printhead carrier disturbance during printing with an imaging apparatus.

SUMMARY OF THE INVENTION

The present invention provides a method for reducing the effects of printhead carrier disturbance during printing with an imaging apparatus.

The invention, in one form thereof, relates to a method for reducing the effects of printhead carrier disturbance during printing with an imaging apparatus having a printhead carrier for carrying at least one printhead. The method includes the steps of accelerating the printhead carrier from a first position in a first direction; printing with the printhead in the first direction; and changing a rate of acceleration of the printhead carrier for a subsequent accelerating of the printhead carrier from the first position in the first direction prior to a subsequent printing with the printhead in the first direction to phase shift the printhead carrier disturbance.

In another form thereof, the invention relates to a method for reducing the effects of printhead carrier disturbance during printing with an imaging apparatus having a printhead carrier for carrying at least one printhead. The method includes the steps of: on a present pass of the printhead across a print medium, accelerating the printhead carrier from a first position in a first direction at a first rate of acceleration; printing with the printhead on the present pass; on a subsequent pass of the printhead across the print medium, accelerating the printhead carrier from the first position in the first direction at a second rate of acceleration different from the first rate of acceleration; and printing with the printhead on the subsequent pass.

In still another form thereof, the invention relates to a method for reducing the effects of printhead carrier disturbance during printing with an imaging apparatus having a printhead carrier for carrying at least one printhead. The method includes the steps of defining a printable region for printing on a print medium, said printable region having a print start position and a print end position, said print start position and said print end position defining an extent of said printable region in a main scanning direction of said printhead carrier; defining a carrier start position outside said printable region; on a present pass of said printhead across said print medium, accelerating said printhead carrier from said carrier start position in a first direction toward said print start position at a first rate of acceleration; printing with said printhead on said present pass; on a subsequent pass of said printhead across said print medium, accelerating said printhead carrier from said carrier start position in said first direction toward said print start position at a second rate of acceleration different from said first rate of acceleration; and printing with said printhead on said subsequent pass.

In still another form thereof, the invention relates to an imaging apparatus. The imaging apparatus includes a printhead carrier system configured to drive a printhead carrier carrying at least one printhead along a bi-directional main scanning direction across a print medium. A controller is communicatively coupled to the printhead carrier system. The controller executes instructions to perform the steps of: on a present pass of the printhead across the print medium, accelerating the printhead carrier from a first position in a first direction at a first rate of acceleration; printing with the printhead on the present pass; on a subsequent pass of the printhead across the print medium, accelerating the printhead carrier from the first position in the first

direction at a second rate of acceleration different from the first rate of acceleration; and printing with the printhead on the subsequent pass.

An advantage of the present invention is an improvement in printing quality by reducing the effects of printhead carrier disturbance, such as for example, a printhead carrier disturbance vibration that would otherwise result in vertical banding, during printing with an imaging apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 graphically illustrates the general concept of a printhead carrier disturbance, in the form of a printhead carrier vibration.

Fig. 2 is a diagrammatic depiction of an imaging system embodying the present invention.

Figs. 3A and 3B show a flowchart of a method in accordance with the present invention.

Fig. 4 is a diagrammatic representation of a printhead carrier scanning across a print medium during a printing pass.

Figs. 5A-5E graphically illustrate, for an exemplary eight pass shingling mode (four passes in each direction), four spatially phase shifted printhead carrier disturbance waveforms attributable to using four different rates of acceleration for a printhead carrier from a carrier start position in four successive printhead passes in the same direction.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate embodiments of the invention, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, and particularly to Fig. 2, there is shown a diagrammatic depiction of an imaging system 10 embodying the present invention.

Imaging system 10 may include a host 12 and an imaging apparatus 14, or alternatively, imaging system 10 may be a standalone system not attached to a host.

Host 12, which may be optional, may be communicatively coupled to imaging apparatus 14 via a communications link 16. Communications link 16 may be established, for example, by a direct cable connection, wireless connection or by a network connection such as for example an Ethernet local area network (LAN).

In embodiments including host 12, host 12 may be, for example, a personal computer including an input/output (I/O) device, such as keyboard and display monitor. Host 12 further includes a processor, input/output (I/O) interfaces, memory, such as RAM, ROM, NVRAM, and may include a mass data storage device, such as a hard drive, CD-ROM and/or DVD units. During operation, host 12 includes in its memory a software program including program instructions that function as an imaging driver, e.g., printer driver software, for imaging apparatus 14. The imaging driver facilitates communication between host 12 and imaging apparatus 14, and may provide formatted print data to imaging apparatus 14. Alternatively, however, all or a portion of the imaging driver may be incorporated into imaging apparatus 14.

Imaging apparatus 14 may be, for example, a printer or a multifunction unit. Such a printer may be, for example, an ink jet printer having an ink jet print engine. Such a multifunction unit may include an ink jet print engine, and is configured to perform standalone functions, such as copying or facsimile receipt and transmission, or may be connected to host 12 via communications link 16 to facilitate a printing function.

Imaging apparatus 14, in the form of an ink jet printer, includes a frame 18, a printhead carrier system 20, a feed roller unit 22, a controller 24, and a mid-frame 26. Imaging apparatus 14 is configured to form an image, e.g., text and/or graphics, on a print medium 28, such as a sheet of paper, transparency or fabric. In embodiments including host 12, formatted print data may be provided to imaging apparatus 14 via communications link 16.

Frame 18 includes a cross member 30, a side frame 32, and a side frame 34, with mid-frame 26 extending between side frame 32 and side frame 34. Cross member 30 also extends between side frame 32 and side frame 34, and may be formed, for example, by providing a stamped metal plate defining a guide surface.

Printhead carrier system 20 includes a carrier drive system 36, a guide member 38, and a printhead carrier 40 that carries a color printhead 42, and a monochrome (e.g., black) printhead 44, for printing on print medium 28. Guide member 38, which may for example be in the form of a smooth metal rod, is coupled to frame 18 via side frame 32 and side frame 34. Each of cross member 30 and carrier guide member 38 support and guide printhead carrier 40, and are considered part of printhead carrier system 20.

A color ink reservoir 46 is provided in fluid communication with color printhead 42, and a monochrome ink reservoir 48 is provided in fluid communication with monochrome printhead 44. Color ink reservoir 46 and color printhead 42 may be combined to form a unitary color printhead cartridge. Likewise, monochrome ink reservoir 48 and monochrome printhead 44 may be combined to form a unitary monochrome printhead cartridge. Alternatively, color ink reservoir 46 and monochrome ink reservoir 48 may be located remote from printhead carrier 40, and respectively connected to their corresponding printheads 42, 44 via fluid conduits.

Feed roller unit 22 includes a feed roller 50 and corresponding idler pinch rollers (not shown). Feed roller 50 is driven for rotation by a drive unit 52. The pinch rollers apply a biasing force to hold print medium 28 in contact with the driven feed roller 50. Drive unit 52 includes a drive source, such as, for example, a direct current (DC) motor, or a stepper motor, and an associated drive mechanism, such as a gear train or belt/pulley arrangement. Feed roller unit 22 feeds print medium 28 in a sheet feed direction 54. As shown in Fig. 2, sheet feed direction 54 is depicted as an X within a circle to indicate that the sheet feed direction 54 is in a direction perpendicular to the plane of Fig. 2, toward the reader. Under the convention adopted for use in describing the present invention, sheet feed direction 54 is parallel to a Y-axis, and thus, sometimes may be referred to as the Y-direction.

Controller 24 is communicatively coupled to color printhead 42 and monochrome printhead 44 via an interface cable 56, such as a flexible ribbon cable. Controller 24 is communicatively coupled to carrier drive system 36 via an interface cable 58. Controller 24 is communicatively coupled to drive unit 52 via an interface cable 60.

Controller 24 includes digital signal processing capability, and may include a processor unit, memory and associated interface circuitry, and may be formed as an

Application Specific Integrated Circuit (ASIC). The controller memory may include, for example, random access memory (RAM), read only memory (ROM), and/or non-volatile random access memory (NVRAM). Controller 24 executes program instructions to effect the printing of an image on print medium 28, such as coated paper, plain paper, photo paper, or transparency, while print medium 28 is supported by mid-frame 26, and is configured to control the operation of printhead carrier system 20 in accordance with the present invention to reduce the effects of printhead carrier disturbance during printing with imaging apparatus 14.

Carrier drive system 36 includes a carrier motor 62, a carrier drive belt 64, a carrier drive pulley 66, and an idler pulley 68. Printhead carrier 40 includes a carrier housing 70. A belt attachment assembly 74 is interposed between carrier drive belt 64 and carrier housing 70, and provides a mechanical interface between carrier drive belt 64 and carrier housing 70.

Printhead carrier 40 is guided by guide member 38 and cross member 30. Printhead carrier 40 is slidably coupled to guide member 38, and is slidably coupled to cross member 30. Guide member 38 defines a bi-directional main scanning direction 78 for printhead carrier 40. Bi-directional main scanning direction 78 is perpendicular to sheet feed direction 54. With reference to the arrangement of components shown in Fig. 2, a left-to-right movement of printhead carrier 40 along bi-directional main scanning direction 78 will be referred to as direction 78a, and a right-to-left movement of printhead carrier 40 along bi-directional main scanning direction 78 will be referred to as direction 78b. Under the convention used in describing the present invention, bi-directional main scanning direction 78, and specific directions 78a and 78b, are parallel to an X-axis, and thus, sometimes may be referred to X-direction 78, 78a and/or 78b.

Carrier drive belt 64 is driven by carrier motor 62 via carrier drive pulley 66, and is supported by an idler pulley 68. Carrier drive belt 64 serves to transmit translation to printhead carrier 40, via belt attachment assembly 74, in a reciprocating manner along guide member 38 and cross member 30 in bi-directional main scanning direction 78. Carrier motor 62 and idler pulley 68 may be mounted to frame 18. Carrier motor 62 may be, for example, a direct current (DC) motor or a stepper motor, and is coupled to carrier drive pulley 66 via a carrier motor shaft 80.

With reference to the arrangement of components shown in Fig. 2, a clockwise rotation of carrier drive pulley 66 results in an indirect application of force to belt attachment assembly 74 via carrier drive belt 64 and idler pulley 68, resulting in a left-to-right movement of printhead carrier 40 along bi-directional main scanning direction 78 in direction 78a. A counter-clockwise rotation of carrier drive pulley 66 results in a direct application of force to belt attachment assembly 74 via carrier drive belt 64, resulting in a right-to-left movement of printhead carrier 40 along bi-directional main scanning direction 78 in direction 78b.

During movement of printhead carrier 40, printhead carrier 40 may experience a printhead carrier disturbance, such as in the form of vibrations, and such vibrations may differ in frequency and/or amplitude depending on the direction of carrier travel. Such vibrations may result in dot placement errors in both the X-direction, i.e., direction 78, and in the Y-direction, i.e., in direction 54, which is perpendicular to the X-direction, and such dot placement errors show up in the printed image formed on print medium 28 in the form of vertical banding.

For example, it has been found in a printhead carrier system, such as printhead carrier system 20 including printhead carrier 40, one source of carrier vibration resulting in carrier induced dot placement error is a fixed frequency natural mode of printhead carrier system 20, which when excited may oscillate at a frequency, for example, of about 50 Hz. The actual frequency of the natural mode of a printhead carrier system will depend on a variety of factors, such as for example, the tolerances and quality of the components used in the printhead carrier system, and the mass of the printhead carrier and mounted printhead cartridges.

Figs. 3A and 3B show a flowchart of a method in accordance with the present invention. For convenience, and without any intent to limit the scope of the invention, the method will be described with printing being effected by printhead 42. Controller 24 may be configured to execute program instructions to perform one or more of the method steps that follow.

The method set forth in the flowchart of Figs. 3A and 3B will be described below with respect to Figs. 4 and 5A-5E. Fig. 4 is a diagrammatic representation of printhead carrier 40 scanning across print medium 28 during a printing pass. In Figs. 5A-5D, waveforms 98a-98d depict printhead carrier velocities, in inches per second (ips), and waveforms 96a-96d depict the shifting, as a result of changing the rate of

acceleration of printhead carrier 40 as shown in waveforms 98a-98d, respectively, of an exemplary printhead carrier disturbance represented in terms of generated dot placement error in microns (um) in the sub-scanning direction, i.e., the Y-direction, at a disturbance frequency of 50 hertz (Hz), i.e., having a period of 20 ms. Fig. 5E shows the superimposed printhead carrier disturbance waveforms 96a-96d of Figs. 5A-5D, thereby demonstrating that the method of the present invention is effective in masking printhead carrier disturbance, such as a printhead carrier disturbance caused by a vibration of printhead carrier 40 at a natural mode frequency of printhead carrier system 20. Each of the exemplary waveforms 96a-96d and 98a-98d is shown with respect to a position, in inches, along bi-directional main scanning direction 78, beginning at carrier start position 94.

At step S100, a printable region 88 (see Figs. 2 and 4) for a sheet of print media, e.g., print medium 28, is defined. Printable region 88 may be defined, for example, by the boundaries of print medium 28 in the main scanning direction 78 with respect to the height of the printhead, e.g., printhead 42. Printable region 88 may include, for example, a print start position 90 and a print end position 92. Thus, print start position 90 and print end position 92 define an extent of the printable region 88 in main scanning direction 78 of printhead carrier 40. As shown, the print start position 90 and a print end position 92 are located with reference to a left-to-right pass of printhead carrier 40; however, for a right-to-left pass of printhead carrier 40, the positions of print start position 90 and a print end position 92 would be reversed from that shown in Fig. 2.

At step S102, a carrier start position 94 is defined at a location outside printable region 88, and is closer to print start position 90 than to print end position 92. Carrier start position 94 may be an arbitrary location selected so as to accommodate the plurality of selectable rates of acceleration for printhead carrier 40 in reaching a steady state printhead carrier velocity, for example, at or prior to print start position 90. One example would be to accommodate a slowest of the plurality of selectable rates of acceleration. In some implementations, however, print start position 90 may be reached prior to reaching the steady state velocity.

At step S104, a frequency of the printhead carrier disturbance (e.g., see waveform 96a of Fig. 5A) for printhead carrier system 20 is determined. The frequency may be determined, for example, by printing a test pattern, and then

measuring the test pattern to determine the frequency of the printhead carrier disturbance experienced by printhead carrier 40. Measuring may be performed manually, or may be performed automatically by using a scanner and pattern recognition software, which is programmed to recognize cyclical patterns in the printed test pattern. In the exemplary waveforms of Figs. 5A-5E, the frequency of the printhead carrier disturbance is 50 Hz.

At step S106, a plurality of acceleration rates are determined, which are based on the frequency of the printhead carrier disturbance determined in step S104. For example, the plurality of acceleration rates may each be different, and may be selected to cause a phase shift of the printhead carrier disturbance frequency in a subsequent printing pass in a particular direction, e.g., direction 78a, relative to a previous printing pass in the same direction, i.e., direction 78a.

As an example, Figs. 5A-5D show, for an eight pass shingling mode, spatially phase shifted printhead carrier disturbance waveforms 96a, 96b, 96c and 96d attributable to using four different rates of acceleration (see acceleration plots 98a, 98b, 98c and 98d) respectively associated with one of the four printing passes in a particular direction, such as one of directions 78a and 78b. Accordingly, in this example, each of PASS 1, PASS 2, PASS 3 and PASS 4 occur with printhead carrier 40 traveling in one direction, e.g., direction 78a. For ease of understanding the present invention, the return passes in direction 78b are not depicted. In the example shown, the rate of acceleration for PASS 2 is greater than PASS 1 and PASS 3, but less than PASS 4; the rate of acceleration for PASS 3 is greater than PASS 1, but less than PASS 2 and PASS 4; and the rate of acceleration for PASS 4 is greater than PASS 1, PASS 2 and PASS 3.

Referring to Figs. 5A-5E, the vertical line at position 0 inches represents carrier start position 94, and the vertical line between positions 1.4 and 1.6 inches represents a particular print position on the page, which may be, for example, print start position 90, or may be some other arbitrary reference location. As shown, print start position 90 represents a predetermined fixed position common to each of the passes in a particular direction, e.g., PASS 1, PASS 2, PASS 3 AND PASS 4. Likewise, carrier start position 94 represents a predetermined fixed position common to each of the passes in a particular direction, e.g., PASS 1, PASS 2, PASS 3 AND PASS 4. As shown, each of the four passes is shifted in order to evenly distribute the

sinusoidal errors of the carrier disturbance. In one preferred embodiment, as illustrated, the shift amounts are in non-sequential order, for example, 0, ½, ¼ and ¾ of the period of the frequency of the carrier disturbance (i.e. providing 0, 180, 90, and 270 degrees phase shift) so as to reduce the appearance of print defects.

In this example, the frequency of the carrier disturbance is 50 Hz, thus the printhead carrier disturbance has a period of 1/50 = 20 milliseconds (ms). Accordingly, in order to shift the phase by 0, ½, ¼, and ¾ of the period of the carrier disturbance, a time required for printhead carrier 40 to travel from carrier start position 94 to print start position 90 is varied by 0 ms, 10 ms, 5 ms, and 15 ms, respectively, in PASS 1, PASS 2, PASS 3 and PASS 4, respectively. Therefore, for example, assuming a distance from carrier start position 94 to print start position 90 of 1.5250 inches and a printhead carrier steady state velocity of 30 inches/second, then acceleration rates of 0.9476, 1.2535, 1.0793, and 1.5 g are required. The phase of the disturbance vibration is given by the equation:

$$\phi = \frac{\mathrm{mod}(t_t, T_d)}{T_d} * 360$$

where ϕ is the phase (in degrees), t_t is the total time to reach the reference point or print start position 90, T_d is the period of the disturbance vibration, and mod is the modulus function (remainder after division). The total time from carrier start position 94 to reach the reference position, e.g., print start position 90, is given by the equation:

$$t_t = \frac{v_{ss}}{a} + \frac{\langle d_r - d_a \rangle}{v_{ss}}$$

$$d_a = \frac{v_{ss}^2}{2a}$$

where v_{ss} is the printhead carrier steady state velocity, a is the carrier acceleration rate, d_r is the known distance from carrier start position 94 to the reference point, e.g., print start position 90, and d_a is the distance required to accelerate. As shown in Figs.

5A-5D, regardless of the rate of acceleration for printhead carrier 40 for each of the passes in a particular direction, the printhead carrier steady state velocity is the same.

The plurality of acceleration rates may be stored, for example, in the memory of controller 24, or alternatively, in host 12, if present.

At step S108, there is selected a first rate of acceleration for printhead carrier 40 from the plurality of acceleration rates for a present pass of printhead 42 across print medium 28, e.g., a sheet of print media, that was determined based on the frequency of the printhead carrier disturbance.

At step S110, on a present pass of printhead 42 across print medium 28, printhead carrier 40 is accelerated from carrier start position 94 in the first direction, e.g., direction 78a, toward print start position 90 at the first rate of acceleration.

At step S112, a portion of an image is printed on print medium 28 with printhead 42 on the present pass.

At step S114, there is selected a second rate of acceleration for printhead carrier 40 from the plurality of acceleration rates for a subsequent pass of printhead 42 across print medium 28, which was determined based on the frequency of the printhead carrier disturbance.

At step S116, on a subsequent pass of printhead 42 across print medium 28, printhead carrier 40 is accelerated from carrier start position 94 in the first direction, e.g., direction 78a, toward print start position 90 at the second rate of acceleration.

At step S118, another portion of the image is printed on print medium 28 with printhead 42 on the subsequent pass.

If desired, controller 24 may execute instructions to control feed roller unit 22 to advance the print medium 28 in sheet feed direction 54 between the present pass of printhead 42 in step S110 and the subsequent pass of printhead 42 at step S116.

Steps S116 and S118 may be repeated as necessary to accommodate a particular print shingling mode. For example, if eight pass shingling is being used in generating the printed image, then four passes will be in one direction, e.g., direction 78a, of bi-directional main scanning direction 78, and four passes with be in the opposite direction, e.g., direction 78b, of bi-directional main scanning direction 78. Of the four passes in a particular direction, each will have associated therewith a rate of acceleration that will differ from the rate of acceleration for the preceding pass and/or the rate of acceleration for a subsequent pass.

As shown in Fig. 5E, the superimposed printhead carrier disturbance waveforms of Fig. 5A-5D demonstrate that the method of the present invention is effective in masking printhead carrier disturbance, such as a printhead carrier disturbance caused by a vibration of printhead carrier 40 at a natural mode frequency of printhead carrier system 20, and thereby reduces the effects of printhead carrier disturbance on printing quality, such as for example, by reducing or eliminating vertical banding in the printed image.

Those skilled in the art will recognize that the order of the selected rates of acceleration for the four passes of the example of Figs. 5A-5E may be changed, as desired, to achieve the most desirable printing result. Also, those skilled in art will recognize that the principles of the present invention may be easily adapted for use in printing modes that have more or less printing passes than in the eight-pass example described above. Still further, those skilled in art will recognize that the principles of the present invention may be easily adapted for use in either or both of printing directions 78a, 78b.

While this invention has been described with respect to particular embodiments, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.